

CLAIMS

What is claimed is:

- 1 1. A method for correcting signals received from an earth formation using a
2 Nuclear Magnetic Resonance (NMR) tool into a borehole in said earth formation,
3 the method comprising:
4 (a) exciting said earth formation with a first pulse sequence having a first
5 recovery time;
6 (b) exciting said earth formation with a plurality of additional pulse sequences
7 having a second recovery time less than said first recovery time;
8 (c) determining from spin echo signals resulting from said additional pulse
9 sequences an estimate of a non-formation signal; and
10 (d) correcting spin echo signals resulting from said first pulse sequence using
11 said estimate and obtaining corrected spin echo signals.
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- 1 2. The method of claim 1 wherein at least one of said additional pulse sequences has
2 a duration less than a duration of said first pulse sequence.
3
- 1 3. The method of claim 1 wherein said second recovery time corresponds to partial
2 recovery of nuclear spins in said earth formation.
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- 1 4. The method of claim 1 wherein said additional pulse sequences comprise clay
2 bound water (CBW) sequences.
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- 1 5. The method of claim 1 wherein said additional pulse sequences have durations
2 less than 40 ms.
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- 1 6. The method of claim 1 wherein said first pulse sequence and said additional pulse
2 sequences comprise CPMG sequences.
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- 1 7. The method of claim 1 wherein said first pulse sequence and said additional pulse
2 sequences comprise modified CPMG sequence having a tip angle of a refocusing
3 pulse that is less than 180°.
4
- 1 8. The method of claim 1 wherein said additional pulse sequences comprise pulse
2 sequences having a plurality of pairs of phase alternated pairs (PAP) of pulse
3 sequences.
4
- 1 9. The method of claim 6 wherein said plurality of pairs of PAP sequences have a
2 specified phase relationship to each other.
3
- 1 10. The method of claim 8 wherein the number of said pairs of PAP sequences nf ,
2 frequency shift between said pairs of PAP sequences δf are related according to:
3
$$nf \cdot \delta f = \frac{m}{t}$$

4 where m is any integer that is not a multiple of nf .
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- 1 11. The method of claim 8 wherein said non-formation signal comprises a ringing
2 from a refocusing pulse.
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- 1 12. The method of claim 8 wherein said non-formation signal comprises a ringing
2 from an excitation pulse.
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- 1 13. The method of claim 11 wherein estimating said ringing from said refocusing
2 pulse further comprises:
3 (i) separately estimating a ringing from each one of said plurality of phase
4 alternated pairs;
5 (ii) forming a vector sum of said separate estimates.
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- 1 14. The method of claim 12 wherein estimating said ringing from said excitation
2 pulse further comprises:
3 (i) separately estimating an echo signal from each one of said plurality of
4 phase alternated pairs; and
5 (ii) forming a vector sum of said separate estimates of said echo signal.
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- 1 15. The method of claim 1 further comprising processing said corrected spin echo
2 signals for determining at least one of (i) a T_2 distribution, (ii) total porosity, (iii)
3 bound volume irreducible, (iv) a T_1 distribution, (v) clay bound water, and, (vi)
4 bound water moveable.
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1 16. The method of claim 1 further comprising conveying said NMR tool into said
2 earth formation on one of (i) a wireline, (ii) a drilling tubular, and, (iii) a
3 slickline.

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1 17. The method of claim 1 further comprising:

2 (i) exciting said earth formation with a second pulse sequence having a
3 recovery time substantially equal to said first recovery time, said second
4 pulse sequence forming a phase alternated pair with said first pulse
5 sequence; and

6 (ii) determining from spin echo signals resulting from said first and second
7 pulse sequences an additional estimate of said non-formation signal.

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1 18. The method of claim 17 further comprising:

2 (A) comparing said estimate and said additional estimate of said non-
3 formation signal; and

4 (B) using a result of said comparison as an indication of a change in said earth
5 formation between positions of said NMR tool at excitation with said first
6 and second pulse sequences.

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1 19. An apparatus for conducting logging operations in a borehole in an earth
2 formation, the apparatus comprising:

3 (a) a magnet on a Nuclear Magnetic Resonance (NMR) tool for polarizing
4 nuclear spins in a region of interest in the earth formation;

5 (b) an antenna on the NMR tool for:
6 (A) exciting said earth formation with a first pulse sequence
7 having a first recovery time;
8 (B) exciting said earth formation with a plurality of additional
9 pulse sequences having a recovery time less than said first
10 recovery time;
11 (c) a processor for
12 (C) determining from spin echo signals resulting from said
13 additional pulse sequences an estimate of a non-formation signal, and
14 (D) correcting spin echo signals resulting from said first pulse
15 sequence using said estimate and obtaining corrected spin echo
16 signals.

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1 20. The apparatus of claim 19 wherein said additional pulse sequences comprise
2 clay bound water (CBW) sequences.

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1 21. The apparatus of claim 19 wherein said additional pulse sequences have
2 durations less than 40 ms.

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1 22. The apparatus of claim 19 wherein said first pulse sequence and said additional
2 pulse sequences comprise CPMG sequences.

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1 23. The apparatus of claim 19 wherein said first pulse sequence and said
2 additional pulse sequences comprise modified CPMG sequence having a tip angle
3 of a refocusing pulse that is less than 180°.

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1 24. The apparatus of claim 19 wherein said additional pulse sequences comprise
2 pulse sequences having a plurality of pairs of phase alternated pairs (PAP) of
3 pulse sequences.

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1 25 The apparatus of claim 24 wherein said plurality of pairs of PAP sequences
2 have a specified phase relationship to each other.

3
1 26 The apparatus of claim 24 wherein the number of said pairs of PAP sequences
2 nf , frequency shift between said pairs of PAP sequences δf are related
3 according to:

4
$$nf \cdot \delta f = \frac{m}{t}$$

5 where m is any integer that is not a multiple of nf .

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1 27 The apparatus of claim 24 wherein said non-formation signal comprises a ringing
2 caused by a refocusing pulse.

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1 28 The apparatus of claim 24 wherein said non-formation signal comprises a ringing
2 caused by an excitation pulse.

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1 29 The apparatus of claim 24 wherein said processor estimates said ringing caused
2 by said refocusing pulse by:

- 3 (i) separately estimating a ringing from each one of said plurality of phase
4 alternated pairs;
5 (ii) forming a vector sum of said separate estimates.
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1 30 The apparatus of claim 25 wherein said processor estimates said ringing caused
2 by said excitation pulse by:

- 3 (i) separately estimating an echo signal from each one of said plurality of
4 phase alternated pairs; and
5 (ii) forming a vector sum of said separate estimates of said echo signal.
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1 31 The apparatus of claim 21 wherein said processor further determines from said
2 corrected spin echo signals at least one of (i) a T_2 distribution, (ii) total porosity,
3 (iii) bound volume irreducible, (iv) bound water movable, (v) clay bound water,
4 and, (vi) a T_1 distribution.
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1 32. The apparatus of claim 19 further comprising a conveyance device for
2 conveying said NMR tool into said borehole, said conveyance device selected
3 from (i) a wireline, (ii) a drilling tubular, and, (iii) a slicline
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1 33. The apparatus of claim 15 wherein said transmitter further excites said earth
2 formation with a second pulse sequence having arecovery time substantially equal

3 to said first recovery time, said second pulse sequence forming a phase alternated
4 pair with said first pulse sequence; and wherein said processor further
5 determines from spin echo signals resulting from said first and second pulse
6 sequences an additional estimate of said non-formation signal.

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1 34. The apparatus of claim 33 wherein said processor further:

2 (i) compares said estimate and said additional estimate of said non-
3 formation signal; and

4 (ii) provides an indication of a change in said earth formation between
5 positions of said NMR tool at excitation with said first and second pulse
6 sequences.

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